22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

TEMPERATURE ANALYSIS IN THE VICINITY OF TRIAXIAL TRAILER DISC BRAKE

D. Perczyński[*], K. Peszyński[*], L. Knopik[**], S. Wawrzyniak[*]

Abstract: *The paper demonstrates the friction nodes statistical analysis of road tractor brakes as well as the temperatures analysis of selected wheel breaking systems. The measurement system consists of six temperature sensors mounted in the vicinity of the friction nodes and seventh to measure the ambient temperature. The output signals of the sensors are transmitted to a digital temperature meter based on ATmega 32 microcontroller. The measurement results were recorded on the SD memory card. The digital temperature sensors of the 1-wire interface manual DS18B20 of Dallas Semiconductor were used to measure the temperature. Moreover, the paper presents the research regarding the wheel temperature dependency of the outside temperature. The Principal Component Analysis was used for statistical testing of brakes temperatures. The method enables the statistical task dimension designation. The dependence analysis between the pairs of wheels was carried out using correlation methods and the spectral analysis of stochastic processes. The study of the coherence function proved that testing system is a linear system with constant parameters.*

Keywords: statistical analysis, road tractor brakes, principal factor analysis, brake temperature.

1. Introduction

The breaking system of a truck is an especially important system for road safety and operation of a vehicle. The intensive experiments and theoretical analysis of the system have been conducted in the Control Division of the Faculty of Mechanical Engineering at UTP University of Science and Technology in Bydgoszcz. It has been assumed that the temperature at the selected point of a wheel brake is a measure of correct operation of the system under operational conditions.

The electronic data acquisition system of temperature from selected friction nodes of the road track disk has been developed. The measuring system consists of six sensors located near friction nodes and 7th measuring the ambient temperature. The sensor output signals are transferred to the digital temperature meter based on ATmega 32 microcontroller. Braking and temperature of friction nodes are not correlated. It is due to the fact that temperature in wheels increases with some delay. Seeking to find the transfer function of the linear system with a binary signal at the input if the system (braking or not) has not given the answer what the transfer function for the system is. The reason of the above is a low correlation between braking and temperature. The analyzed process was observed at the $T_{\mathrm{ob}} = 2240\,\mathrm{s}$. Total period of braking was $T_{\mathrm{h}} = 39\,\mathrm{s}$.

2. Mathematical model

[*]Assist. Prof. Daniel Perczyński, PhD.: UTP University of Science and Technology, Faculty of Mechanical Engineering, Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz; PL, daniel.perczynski@utp.edu.pl

[*]Assoc. Prof. Kazimierz Peszynski, PhD.: UTP University of Science and Technology, Faculty of Mechanical Engineering, Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz; PL, kazimierz.peszynski@utp.edu.pl

[**]Assoc. Prof. Leszek Knopik, PhD.: UTP University of Science and Technology, Faculty of Management, Fordońska 430, 85-790 Bydgoszcz, PL, leszek.knopik@utp.edu.pl

[*]Assist. Prof. Sylwester Wawarzyniak, PhD.: UTP University of Science and Technology, Faculty of Mechanical Engineering, Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz; PL, sylwester.wawrzyniak@utp.edu.pl

The matrix of correlation coefficients is determined for a random variable $(T_1, T_2, T_3, T_4, T_{5,} T_{6,} T_z, H)$, where T_i $(i = 1, 2, \ldots, 6)$ is temperature of i^{th} fraction node, T_z – ambient temperature, H – binary signal ($H(t) = 1$ – braking, $H(t) = 0$ no braking). The values of obtained coefficients are presented in Table 1.

Tab. 1. Matrix of correlations between temperature and braking

	T_1	T_2	T_3	T_4	T_5	T_6	T_z	H
T_1	1.000							
T_2	0.997	1.000						
T_3	0.980	0.979	1.000					
T_4	0.996	0.997	0.980	1.000				
T_5	0.948	0.946	0.989	0.951	1.000			
T_6	0.997	0.998	0.977	0.999	0.945	1.000		
T_z	0.818	0.801	0.865	0.827	0.912	0.814	1.000	
H	-0.055	-0.048	-0.063	-0.039	-0.063	-0.040	-0.065	1.000

The analysis of the correlation matrix results shows that the correlation coefficients between wheel temperatures are very high, the correlation coefficients between wheel temperatures and the outside temperature are a little bit lower, but still high. The correlation coefficients between wheel temperatures and braking are not significant.

The statistical data $(T_1, T_2, T_3, T_4, T_{5,} T_{6,} T_z)$ are measurable and all of them are measured in degrees Celsius, while the characteristic H is binary dimensionless. A large number of statistical hypothesis based on the assumption of normality features can be tested for measurable characteristics. Significance of the correlation coefficients and the dimensionality of space is carried out by the principal component analysis. The correlation matrix for the characteristics $(T_1, T_2, T_3, T_4, T_{5,} T_{6,} T_z)$ contains high values of the correlation coefficients. Therefore, the question arises if seven-dimensional space of the characteristics $(T_1, T_2, T_3, T_4, T_{5,} T_{6,} T_z)$ is not redundant? The research attempts to answer the question by using the principal component analysis.

3. Principal component analysis

The principal component analysis consists in converting the input observations into the new unobservable variables. The new variables are uncorrelated. Each of the principal components is a linear combination of input variables. The principal components are arranged in the way that variances of further components get smaller and smaller. Usually the first few principal components give the most information about an examined phenomenon. The key assumptions of the method should be verified before starting the principal components analysis. The method is applicable when the correlation between variables are relatively high. The basic assumption is the normality of data. In the analyzed phenomenon the normality of tested data is ensured and, furthermore, there is a large number of analyzed test sample, $n = 2240$. There is given the matrix $\mathbf{X}$ with dimension of l_e lines for l_z columns, where: l_e – the number of experiments and l_z – the number of variables. For analyzed data there is $l_e = 2240$ and $l_z = 7$. $Y(i)$ means the average value in i^{th} column of the matrix $\mathbf{X}$. We create the matrix $\mathbf{X}_c$ based on the matrix $\mathbf{X}$ by subtracting the average value of $Y(i)$ in the column from each element of the matrix $\mathbf{X}$.

We make the matrix $\mathbf{S} = (\mathbf{X}_c{}^T \mathbf{X}_c)/(l_e - 1)$ known as a covariance matrix of a random vector $(T_1, T_2, T_3, T_4, T_{5,} T_{6,} T_z)$. The solution of the equation $\det(\mathbf{S} - \lambda \mathbf{I}) = 0$, where $\mathbf{I}$ is the identity matrix, are the eigenvalues of the matrix $\mathbf{S}$. The matrix $\mathbf{S}$ is a symmetrical matrix and positive definite. This is due to the fact that there are $l_z = 7$ actual and non-negative eigenvalues $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq, \ldots, \geq \lambda l_z$. The following values has been calculated for the data analyzed in the paper: $\lambda_1 = 6.6420,\ \lambda_2 = 0.3017,\ \lambda_3 = 0.0478,\ \lambda_4 = 0.0048,\ \lambda_5 = 0.0018,\ \lambda_6 = 0.0011, \lambda_7 = 0.0005$. Analysis of eigenvalues shows that the first eigenvalue is much higher than the other values.

4. Correlation analysis of temperature change process

The following part of the paper is dedicated to the relations between stochastic processes, especially processes regarding the changes of temperature values in the braking system of the trailer. Testing the processes and determining the characteristic of the process is possible, because the measurement data of the implemented process are available. The analysis contains $n = 2240$ temperature measurements, 6 process implementations every $\Delta t = 1\text{s}$. For testing the temperature signal accordance of the friction nodes on one of vehicle disk, we determine the coherence function specified by the formula (Bendat J.S., Piersol A.G. 1976):

$$\gamma_{xy}^2(\omega) = \frac{|S_{xy}(\omega)|^2}{S_{xx}(\omega)S_{yy}(\omega)} \tag{1}$$

where $S_{xx}(\omega)$ and $S_{yy}(\omega)$ are the spectral densities of temperature and braking, which are determined by formulas

$$S_{xx}(\omega) = \int_{-\infty}^{\infty} R_{xx}(\tau) e^{-j2\pi\omega} d\tau \tag{2}$$

$$S_{yy}(\omega) = \int_{-\infty}^{\infty} R_{yy}(\tau) e^{-j2\pi\omega} d\tau \tag{3}$$

where $R_{xx}(\tau)$ is the autocorrelation function determined as an average value:

$$R_{xx}(\tau) = E\{X(t)X(t+\tau)\}$$

The above formula can be written in limit form: $R_{xx}(\tau) = \lim\limits_{T\to\infty} \frac{1}{T}\int_0^T x(t)x(t+\tau)dt$

The value $R_{xx}(0) = E\{X(t)^2\}$ is known as a mean square value of the process $X(t)$. Simultaneously, the mean square value of the process $X(t)$ is defined as:

$$R_{xx}(0) = \int_{-\infty}^{\infty} S_{xx}(\omega)d\omega$$

On the other hand, $S_{xy}(\omega)$ and $S_{yx}(\omega)$ are mutual spectral densities:

$$S_{xy}(\omega) = \int_{-\infty}^{\infty} R_{xy}(\tau) e^{-j2\pi\omega} d\tau \tag{4}$$

$$S_{yx}(\omega) = \int_{-\infty}^{\infty} R_{yx}(\tau) e^{-j2\pi\omega} d\tau \tag{5}$$

where $R_{xy}(\tau)$ is the cross-correlation function (mutual correlation) determined as an average value: $R_{xy}(\tau) = E\{X(t)Y(t+\tau)\}$, the coherence function satisfies the condition $0 \le \gamma_{xy}^2(\omega) \le 1$, for the linear system with constant parameters $\gamma_{xy}^2(\omega) = 1$ (Morrison D.F. 1990).

The calculated value of the coherence function is constant and approximately equal 1. In practice, it is very important to determine the autocorrelation function $R_{xx}(\tau)$ and the correlation function of measuring data. An unbiased estimator of the autocorrelation function $R_{xx}(\tau)$ is the statistics (Krzyśko M., 2000)

$$\hat{R}_{xx}(rh) = \frac{1}{N-r}\sum_{n=1}^{N-r} x_n x_{n+r} ,$$

where: $x_1, x_2, x_3, \ldots, x_n$ are the measurements of implemented process $X(t)$ measured by the constant step $h = \Delta t$. An unbiased estimator of the cross-correlation function $R_{xy}(\tau)$ is the statistics

$$\hat{R}_{xy}(rh) = \frac{1}{N-r}\sum_{n=1}^{N-r} x_n y_{n+r}$$

where $y_1, y_2, y_3, \ldots, y_n$ are the measurements of implemented process $Y(t)$ measured by the constant step h. The formulas (2), (3), (4) are (5) implemented by the Fourier transform.

It is much easier to test the relations between the temperatures in the friction nodes than between temperature and braking. The Fig. 2 presents the value diagrams of the cross-correlation function for pairs of wheels from one disk (1, 2), (3, 4) and (5, 6). The diagrams have the same characteristic, however, clear differences between the disks can be noticed.

5. Conclusions

The temperatures values in the function of time presented in the paper are seen as a stochastic process, while the temperature changes for each friction node constitute implementation of this process.

The correlation matrix determined for the vector $(T_1, T_2, \ldots T_{6,})$ shows that all of the correlations are strongly significant. However, the correlation coefficient values are different for different pairs (T_i, T_j).

It has been proved that the use of the principal component analysis for the set of friction node temperatures is intentional, because the method shows redundancy of analyzed sample. It is the result of high correlation of the temperature processes in the vehicle wheels. The use of the correlation analysis for the processes of temperature changes in friction nodes of the braking system has explained the relation between temperatures and has given the basis for future research in this task. The previous research has been confirmed by the transfer function defined in the paper.

References

Bendat J.S., Piersol A.G. (1976): Metody analizy i pomiaru sygnałów losowych (Eng. Measurements and Analysis of Random Data). PWN, Warszawa.

Krzyśko M. (2000): Wielowymiarowa analiza statystyczna (Eng. Multivariate statistical methods), Wydawnictwo Naukowe UAM, Poznań.

Morrisom D.F. (1990): Wielowymiarowa analiza statystyczna (Eng. Multivariate statistical methods, New York: McGraw-Hill), PWE, Warszawa.